NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NO 1066

FREQUENCY RESPONSE AND DISTORTION MEASUREMENT OF HEADSETS FOR USE IN AUDITORY SONAR DISPLAYS

by

J. S. Russotti, G. B. Haskell, R. Neal, T. P. Santoro
and
S. M. Carpenter

Naval Medical Research and Development Command
Research Work Unit M0933.004-0006

Released by:

C. A. Harvey, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

22 November 1985

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Project 64117N M0933 M0933 004 0006

Approved and Released by

C. A. Harvey

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Commanding Officer
NAVSUBMEDRSCHLAB

SUMMARY PAGE

PROBLEM

This research was prompted by the need to select a suitable headset for auditory processing of passive sonar information. Essential to making such selection is the accurate measurement of headphone frequency response as worn on the average listener. No standard for such measurement exists.

FINDINGS

We evaluated 24 commercially available headsets for suitability in accurately presenting auditory sonar information. The evaluation employs a digitized transfer-function correction technique, which was developed in-house and reported in a previous paper. Eleven headset models exhibiting the most linear corrected frequency response, 10 to 16 dB total variation, were further evaluated for total harmonic distortion. All earphone measurements were made using a commercially available acoustic test mannikin containing an ear simulating coupler.

APPLICATION

This electroacoustic information is of value in sonar headset selection for optimal transfer of the acoustic signal to the listener. Keywords: → to 1473

ADMINISTRATIVE INFORMATION

This research was carried out under Naval Medical Research and Development Command Work Unit 64117N M0933 M0933 004 0006, "Development of engineering specificaitons for optimum auditory classification/detection through headphones." It was submitted for review on 8 August 1985, approved for release on 22 November 1985, and designated as NSMRL Report Number 1066.

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Abstract

Because American National Standards Institute measurement standards cannot be applied to modern commercial headsets, which generally are built to nonstandard designs, a new procedure had to be devised. That procedure, described in another report, provides the earphone element with an acoustic load similar to the one provided by a human wearer. Using this technique, 24 headset models were each tested 20 times for frequency response between 40 and 10000 Hz, the limits within which the system matches the acoustic loading of the human ear. The results permitted us to choose the 11 models with the flattest frequency responses: 3 models show a total variation of 11 dB or less, and the other 8 vary by no more than 16 dB. For the top 11 models, harmonic distortion (for a 95-dB SPL, 1-kHz test tone) ranged from .03% to .75%, far better than we expected; nine of the 11 top models had distortion levels less than .1%.

Frequency response and distortion measurement of headsets for use in auditory sonar displays

J. S. Russotti, C. B. Haskell, R Neal, T. P. Santoro,
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The earphone element in the H157-158AIC headset (U. S. Army, 1973; USAF, 1962, MIL H-26312A; USAF, 1962, MIL H-26541A) currently used on BQQ-5 sonar systems was designed to meet electroacoustic standards specified by the United States Air Force (1957). Although these specifications were updated 20 years later (USAF, 1977, MIL E-25670A), the earphone element retains essentially the same bandwidth (100 to 5500 Hz) and harmonic distortion (3% or less from 100-2,000 Hz and 5% or less from 2000-5000 Hz) (USAF, 1977, MIL E-25670/1; USAF, 1977, MIL E-25670/2). These earphone specifications do not exploit the full capability of the available audio signal obtainable from modern passive-sonar hydrophones.

Such frequency bandwidth limitations severely reduce a sonar operator's discrimination and detection performance. Low-pass filtering that removes frequencies above 3 kHz, 4kHz, or 6kHz leads to significant reduction in sonar-target discrimination in sea-state noise (Harris, Kerivan, & Russotti, 1979).

Since information critical to detection and discrimination exists at these higher frequencies, a sonar operator's earphones should be capable of presenting information in that range, and they should do so without changing the received signal. Any desired signal enhancement can be introduced into the electrical signal that drives the headset. Furthermore, a headset with a linear frequency response is needed for open-band search procedures where the absence of operator selected filtering is specified.

American National Standards Institute (ANSI) (1973) devices and techniques are available for laboratory and for audiometric earphones, but they are not intended for currently available commercial headsets, most of which are built to nonstandard designs. The ANSI standards specify devices that couple microphone to earphone without modeling the mechanics of the human auditory mechanism. On a human wearer, an earphone element is loaded by ear-canal resonances and eardrum and ossicular-chain compliances in a more complex fashion than a single-chamber coupler can provide. Further, the human head and pinna are not much like the machined surface of an ANSI coupler.

Using probe-tube techniques, Shaw and Thiessen (1962) and Shaw (1966) measured the sound pressures developed under circumaural earphones on human wearers and on then-available couplers. The real-ear measurements demonstrated that the couplers were not providing accurate frequency-response curves.

After detailed information on the acoustic impedance of the human ear became available, a number of workers developed "ear simulators" that used multiple resonant cavities to present a more accurate impedance load to the earphone. Zwislocki's (1957) research on the impedance of the eardrum resulted in his developing (1970, 1971) a 4-chamber ear simulator; it is commercially available and has been the object of numerous comparisons with real-ear data.

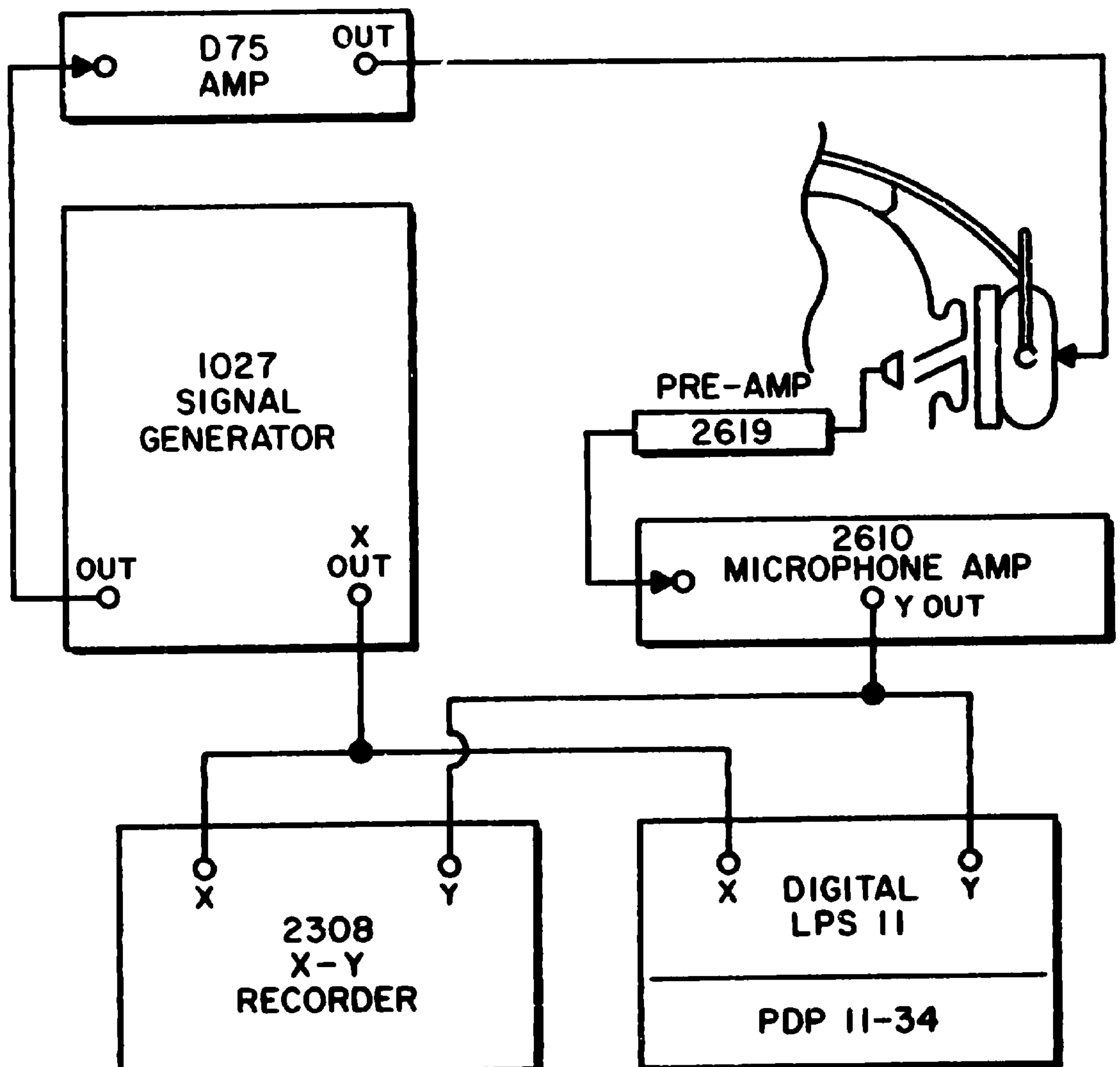
Burkhard and Sachs (1974) incorporated the eardrum-simulating portion of the Zwislocki coupler into an anthropometrically average mannikin, KEMAR. A flexible silicone-rubber pinna and connecting metal ear canal replaced the corresponding upper portions of the Zwislocki ear-simulator. Burkhard (1975) modified the construction in order to produce a device with more stable acoustic characteristics. Acoustic measurements on KEMAR agree with average measurements on human subjects (Shaw, 1974).

The machined surfaces of the pinna-simulating portion of the Zwislocki coupler were designed for audiometric and laboratory earphones with supraaural cushions. A flat-plate adapter is designed for earphones with circumaural cushions. Unfortunately, many commercial headsets don't use the usual audiometric or laboratory sorts of cushions and so are untestable on the standard Zwislocki coupler. The modified Zwislocki coupler provided on KEMAR is a more appropriate choice for testing all the types of headsets that might be encountered. And because of KEMAR's anthropometrically average dimensions, not only the earphone element, but the effects of the cushion or muff and of the headband are sampled.

However, frequency-response tests that use an ear simulator require a transfer-function correction because the complex impedances of the human-ear model make the frequency response nonlinear. Such a correction procedure is detailed in a previous report (Russotti, et al., 1985). The current study uses that procedure.

Method

Figure 1 diagrams the frequency-response measurement system. A Bruel and Kjaer (B&K) 4134 1/2-in. condenser microphone at the mannikin's eardrum fed a B&K 2619 preamplifier. A B&K 2610 measuring amplifier changed the microphone output into a signal for the Y axis of a B&K 2308 X-Y recorder. A swept sinusoid from a B&K 1027 signal


D75
AMP
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1027
SIGNAL
GENERATOR
OUT
X
OUT
PRE-AMP
2619
2610
MICROPHONE AMP
Y OUT
X
Y
2308
X-Y
RECORDER
X
DIGITAL
LPS 11
Y
PDP 11-34

Figure 1

generator (amplified by a Crown D75 power amplifier) provided the headset's signal and the signal for the X axis. A Digital Equipment Corporation (DEC) LPS11 A/D converter (PDP11/34 peripheral) also received the X and Y voltages. A B&K 4220 pistonphone was used for calibration.

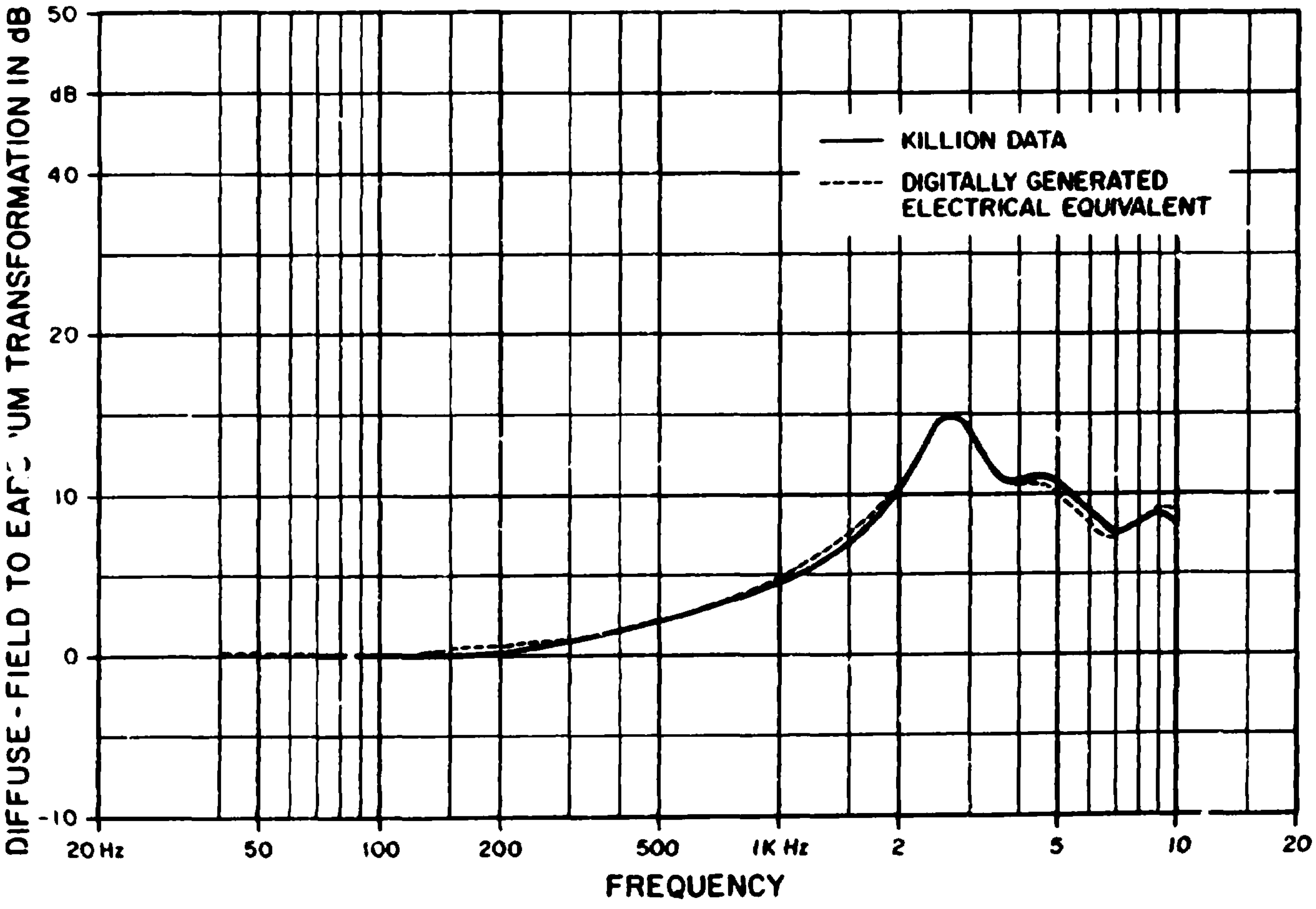
The solid line in Figure 2, from Killion's (1979) work on the random-incidence sound-pressure response of the mannikin ear at eardrum position, graphs a transfer function that describes the resonance of the pinna and the energy change produced by the ear canal. The dotted line shows our digitized electrical equivalent. The DEC PDP11 was programmed to subtract this transfer function from earphone response curves (Russotti, et al., 1985)

Figure 3 shows the mannikin with a headset under test. A plywood yoke with hard-rubber pads prevented any low-frequency accelerometer effect.

A constant-amplitude sinusoidal signal, swept from 40-10000 Hz, was fed to each tested earphone at a level adjusted to 80 dB SPL at 1000 Hz in a Zwislocki coupler modified for use in an acoustic test mannikin, KEMAR. Five response measurements were made on each earphone element for two samples of each headset model under test. By combining data on left and right earphone elements, we were able to collect a total of 20 measurements for each model.

A series of concentric marks around the mannikin's ear aided in centering the earphone over the entrance to the ear canal. Whenever a headset was placed (or replaced) on KEMAR's ears, the rigid plywood yoke was adjusted: its two side pads were placed as close as possible to the centers of the earphones without binding or moving the phones. When the adjustment was done properly, the yoke could still be moved. Following each test, the headset was removed.

Figure 4 diagrams the distortion-measurement system, which was used in an anechoic chamber. The same B&K 4134, 2619, 2610 microphone, preamplifier, and measuring amplifier components were used to measure the signal received at the eardrum. A Hewlett Packard (HP) 339A distortion analyzer provided the frequency to be tested; a Crown D75 amplifier drove the earphone under test. The measuring amplifier's output was fed back to the HP 339A for distortion analysis. Distortion analyzer output was monitored on a B&K 2033 spectrum analyzer to ensure that no extraneous signals were mistakenly measured as distortion components. The measuring system's own distortion was 76.5 dB below the fundamental at 1 kHz, well below earphone distortion levels. Before each measurement, the activated earphone was positioned for maximum response level. The yoke was also put in place. Then a 1-kHz tone was adjusted to 95 dB SPL. Three measurements were made on each


DIFFUSE - FIELD TO EAR DRUM TRANSFORMATION IN dB
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dB
40
20
10
0
-10
KILLION DATA
DIGITALLY GENERATED ELECTRICAL EQUIVALENT
20 Hz
50
100
200
500
1K Hz
2
5
10
20
FREQUENCY

Figure 2

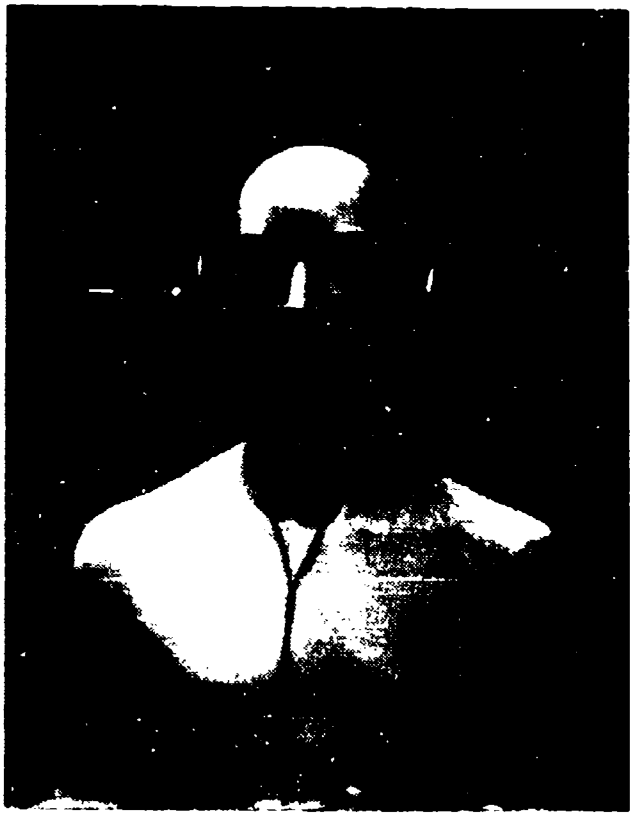


Figure 3

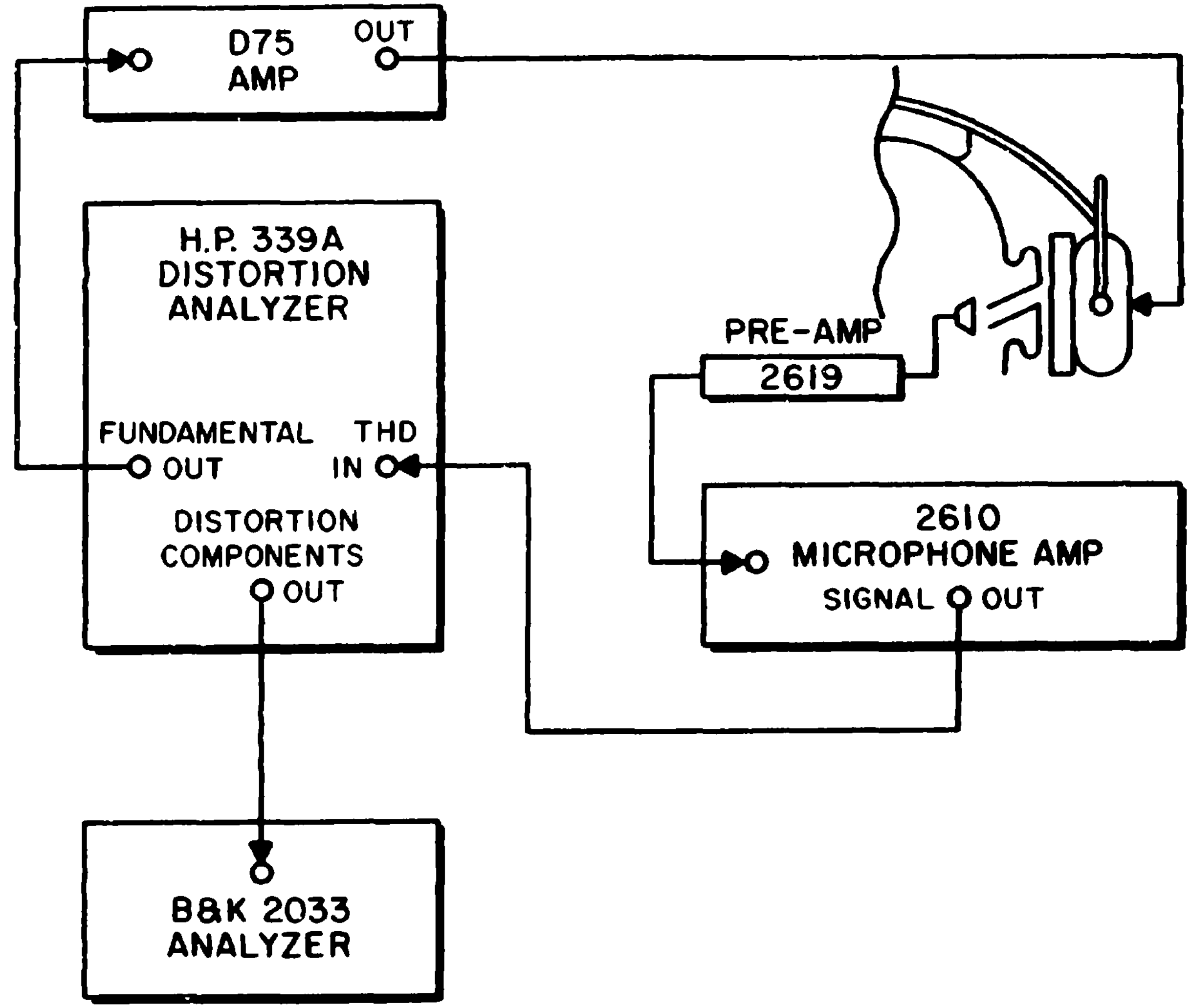

D75
AMP
OUT
H.P. 339A
DISTORTION
ANALYZER
FUNDAMENTAL
OUT
THD
IN
DISTORTION
COMPONENTS
OUT
PRE-AMP
2619
2610
MICROPHONE AMP
SIGNAL
OUT
B&K 2033
ANALYZER

Figure 4

earphone element for two samples of each headset model under test. By combining data on left and right earphone elements, we were able to collect a total of 12 measurements for each model. Following each test, the headset was removed.

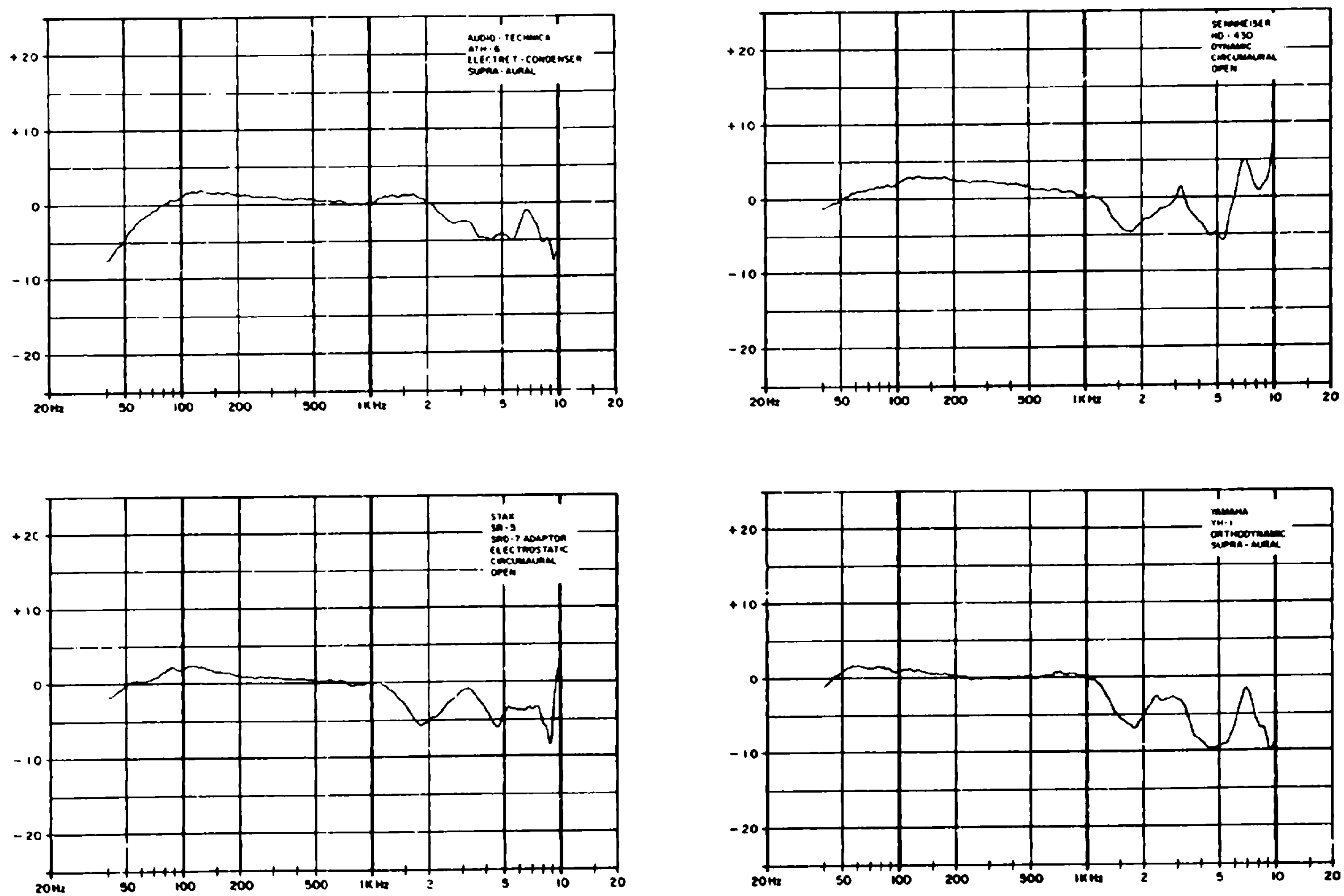
Top-of-the-line headsets (as determined from the manufacturers' own specifications) were tested. Selection was made without regard to transducer type, cushion type, headset design, impedance requirements, or whether the phone was designed to attenuate outside sound. Twenty-four headset models were chosen. Primary interest was to determine how well currently available headsets respond when fitted to an average wearer.

Results

Figures 5, 6, and 7 present the corrected average frequency-response characteristics from 40-10000 Hz for the 11 models best in frequency response. Table 1 presents the average total harmonic distortion and the frequency-response variability for these 11 models. Appendix 1 presents the corrected average frequency-response characteristics for the remaining 13 models.

Conclusions

A technique for frequency response measurement of headsets has been applied in evaluating 24 commercially produced models. Based upon averaged frequency response in the range 40-10000 Hz, the top 11 ranking models were further evaluated for total harmonic distortion. For applications where comparatively flat frequency response is of importance, selection from among these models is suggested. Averaged frequency response characteristics for the remaining 13 models is provided for comparison. For applications where the electrical signal is of narrower bandwidth, these other models may have application.


AUDIO - TECHNICA
ATH - 6
ELECTRET - CONDENSER
SUPRA - AURAL
SENNHEISER
HD - 430
DYNAMIC
CIRCUMAURAL
OPEN
STAX
SR - 5
SRD - 7 ADAPTOR
ELECTROSTATIC
CIRCUMAURAL
OPEN
YAMAHA
YH - 1
ORTHODYNAMIC
SUPRA - AURAL
+20
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20 Hz
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1K Hz
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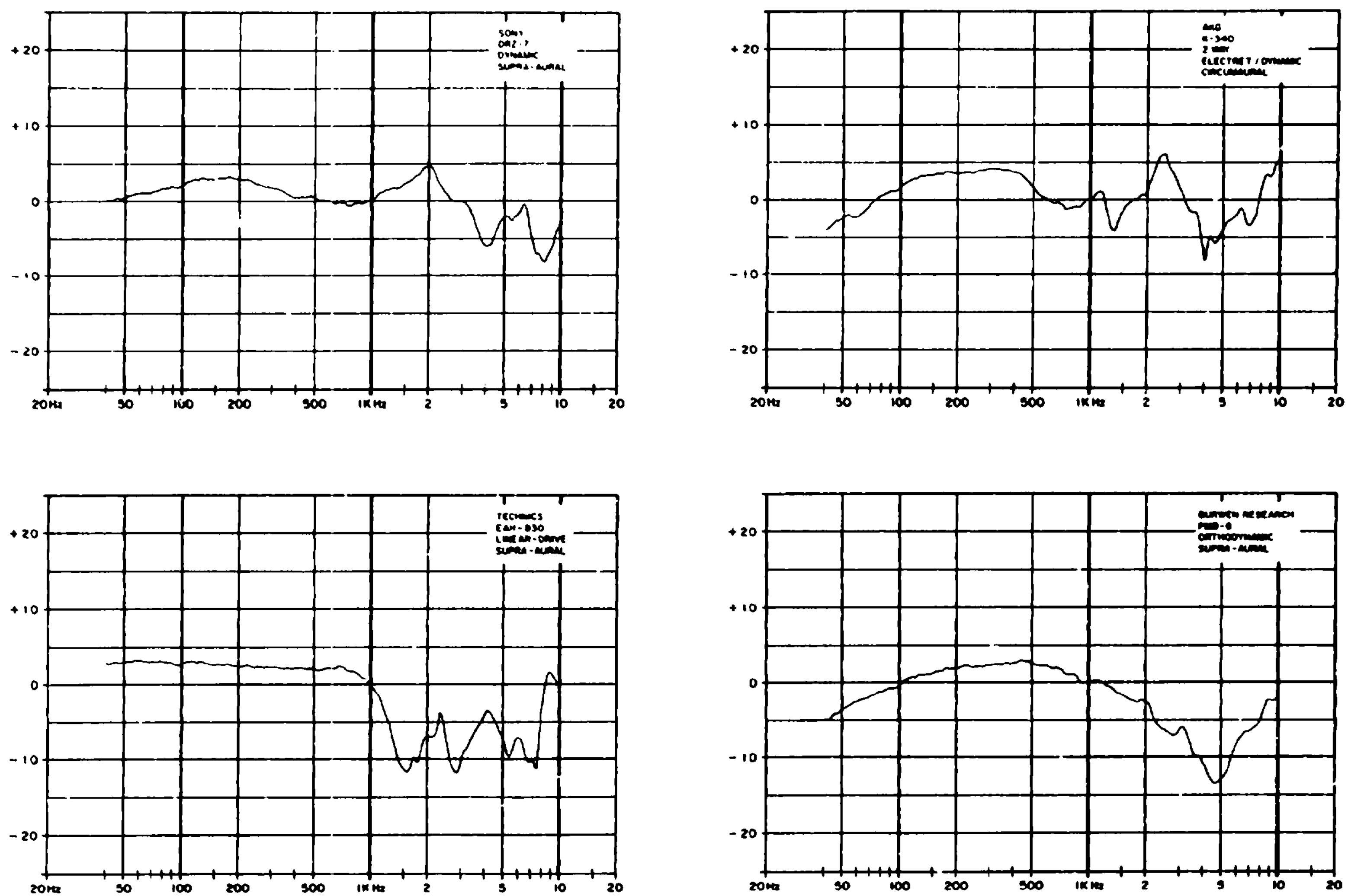
20

Figure 5


SONY
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SUPRA-AURAL
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TECHNICS
EAH-830
LINEAR-DRIVE
SUPRA-AURAL
BURWEN RESEARCH
ORTHODYNAMIC
SUPRA-AURAL
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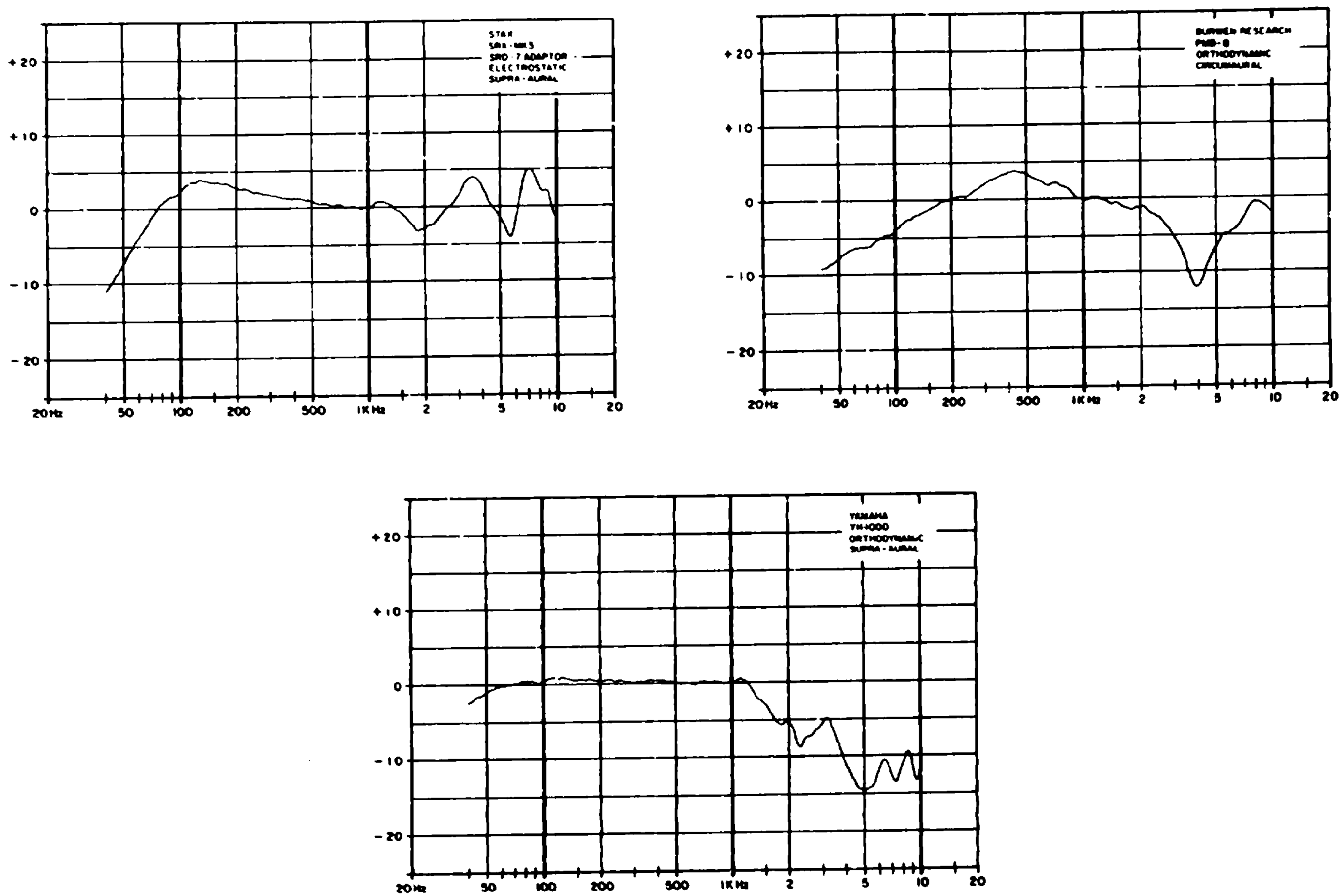
Figure 6


STAX
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SRD-7 ADAPTOR
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1K Hz
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Figure 7

TABLE I

MANUFACTURER	MODEL	RESPONSE VARIATION 40 Hz – 10 kHz	THD-1kHz 95 dB SPL AT EARPHONE
AUDIO TECHNICA	ATH 6	10 dB	.18%
SENNHEISER	HD 430	11 dB	.05%
STAX	SR-5	11 dB	.06%
YAMAHA	YH-1	12 dB	.02%
SONY	DR-Z7	13 dB	.03%
AKG	K 340	14 dB	.75%
TECHNICS	EAH-830	15 dB	.03%
BURWEN RES.	PMB-6	16 dB	.06%
STAX	SR-X MK-3	16 dB	.07%
BURWEN RES.	PMB-8	16 dB	.05%
YAMAHA	YH 1000	16 dB	.03%

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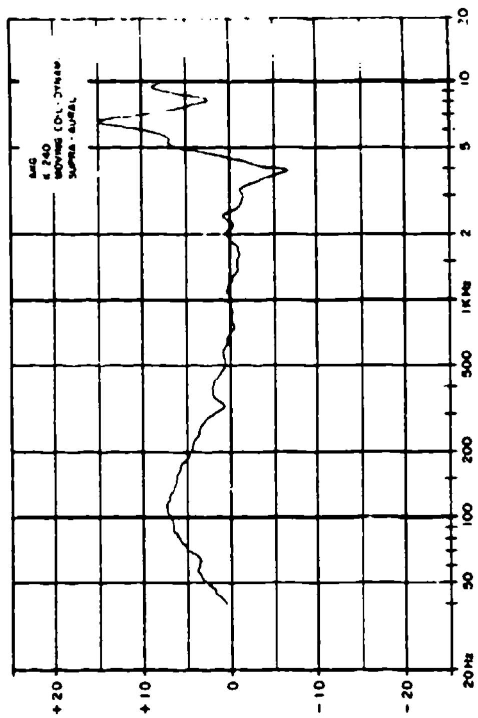

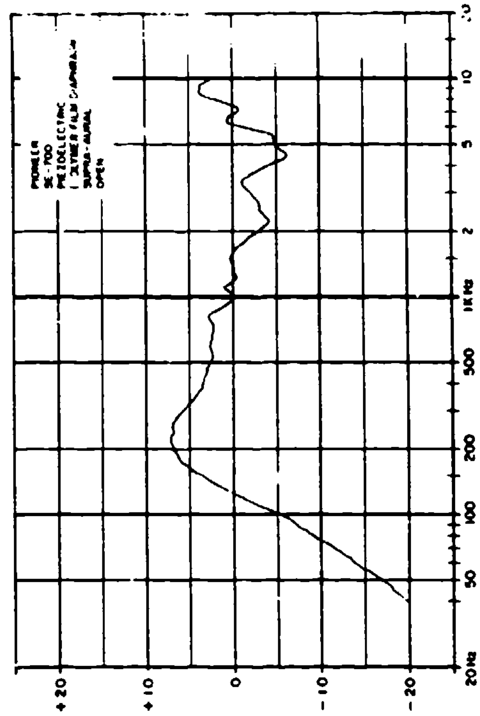

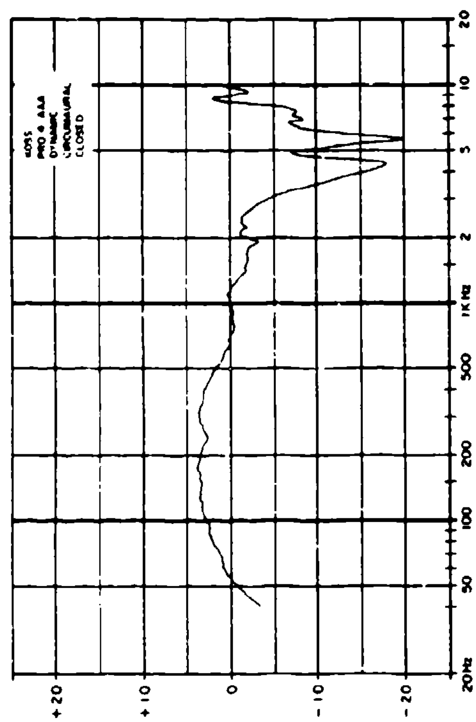

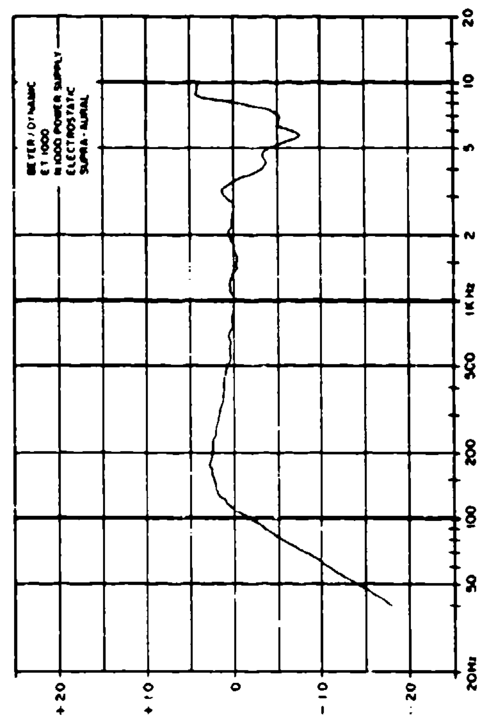

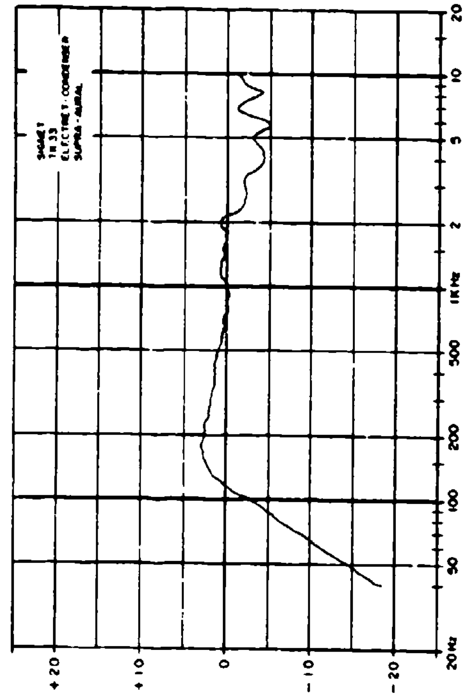
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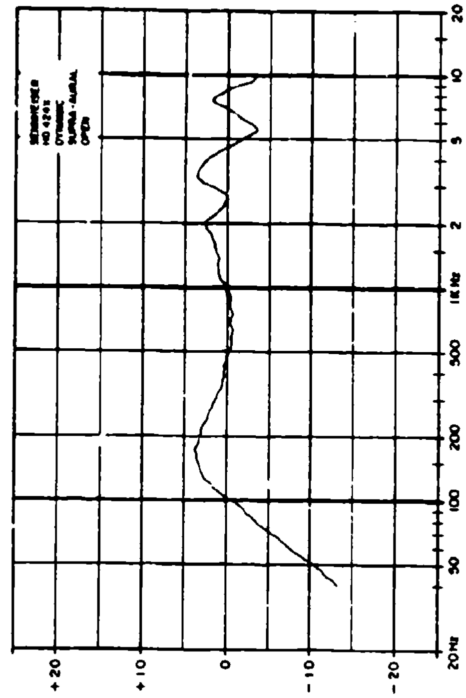
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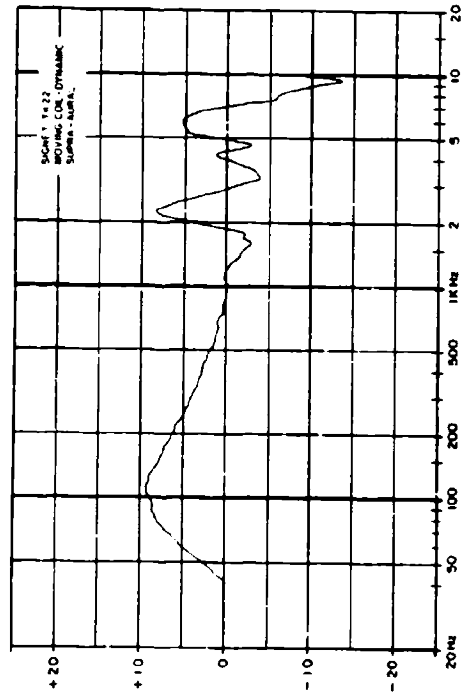
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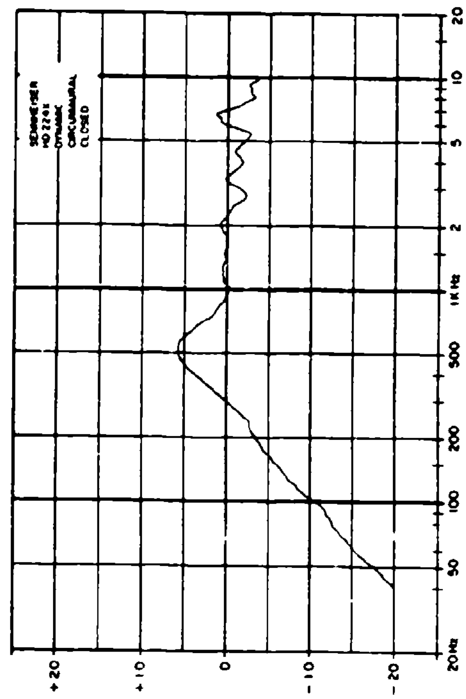
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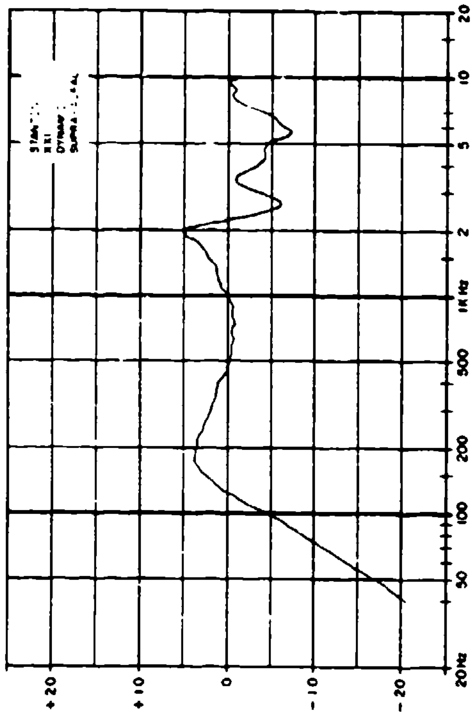

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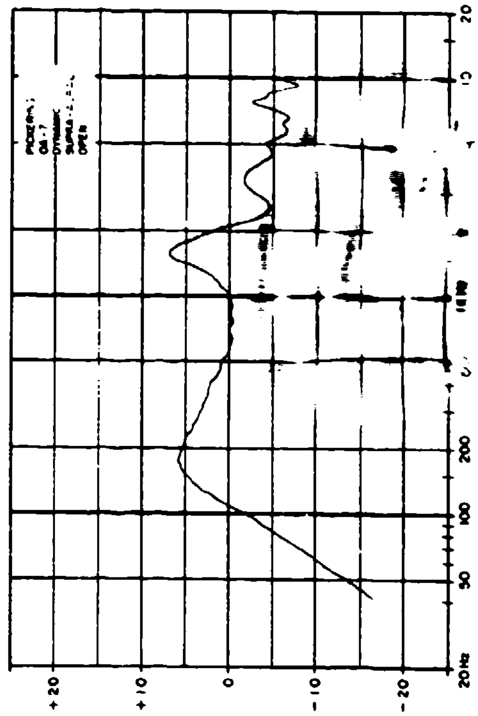

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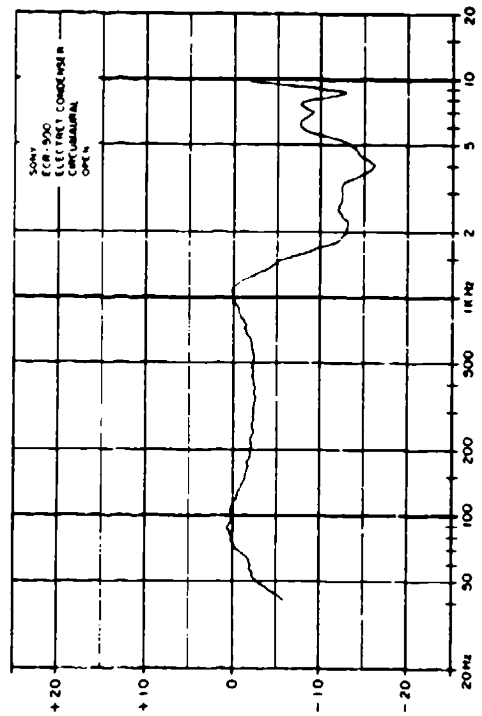

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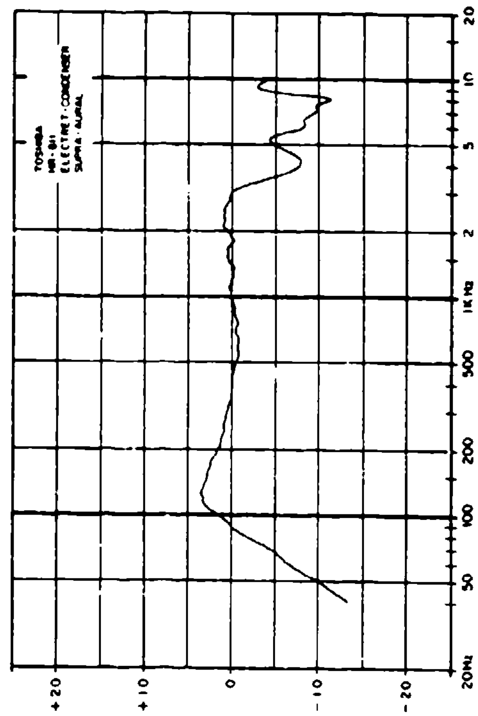

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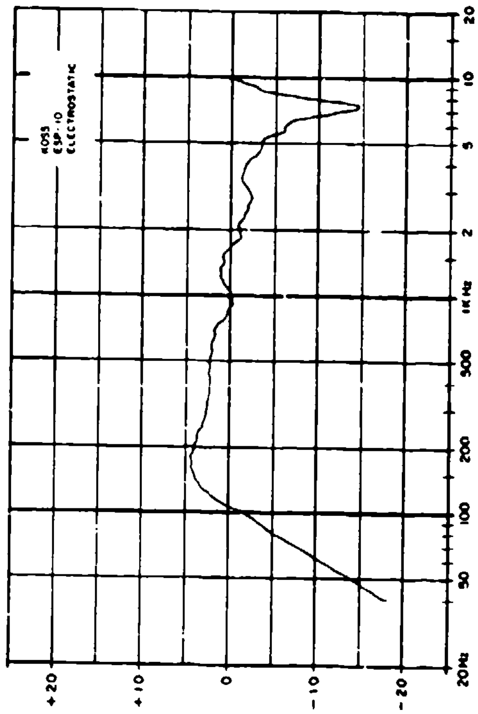
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	6. PERFORMING ORG. REPORT NUMBER: NSMRL Report # 1066
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Sonar, Passive sonar, Aural detection, ~~Headsets, Headset measurement,~~ Distortion measurement, ~~Electroacoustics, Auditory processing.~~

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Because American National Standards Institute measurement standards cannot be applied to modern commercial headsets, which generally are built to nonstandard designs, a new procedure had to be devised. That procedure, described in another report, provides the earphone element with an acoustic load similar to the one provided by a human wearer. Using this technique, 24 headset models were each tested 20 times for frequency response between 40 and 1000 Hz, the limits within which the system matches the acoustic loading of the human ear.

20 cont'd

The results permitted us to choose the 11 models with the flattest frequency responses: 3 models show a total variation of 11 dB or less, and the other 8 vary by no more than 16 dB. For the top 11 models, harmonic distortion (for a 95-dB SPL, 1-kHz test tone) ranged from .03% to .75%, far better than we expected; nine of the 11 top models had distortion levels less than .1%.